

SOME NUCLEAR DISINTEGRATIONS

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ABSTRACT. Endothermy and exothermy of several nuclear disintegrations have been studied. The radioactive nuclei show pronounced exothermy with a release of energy per disintegration ranging from 165 Mev to 236 Mev according to the structure assigned to the nucleus. The potential depth within the nucleus varies from about 4×10^{-18} for the stable nuclei to 10^{-20} for the unstable radioactive nuclei.

The following is a study of the endothermy and exothermy of several nuclear disruptions, particularly of the radioactive nuclei, in light of the hypothesis advanced by the writer (Soonawala, 1929, 1942). There can be little doubt that a nucleus is made up of smaller constituents, and the protons and neutrons can be the smallest of these. If the sum of the masses of the constituents is greater than that of the nucleus, energy is required to break up the nucleus and the process is endothermic. This energy is equivalent to the difference of the masses of the nucleus and its constituents. On the other hand, if the nucleus is synthesised from its constituents, a similar amount of energy would be released and the process would be exothermic. Also energy is liberated in the fission of a nucleus of mass greater than the combined masses of its constituents. In the study of atomic nuclei presented before, it was shown that the rare gas nuclei are, in all probability, the constituents of the majority of the nuclei; and to these, the lighter particles such as alpha particles, neutrons and protons are added to make up the remaining nuclei. We may now consider whether the disruption of the various nuclei can be endothermic or exothermic. We shall consider the main groups of elements obtained by the synthesis of the rare gas nuclei, and the result is presented in Table I. One nucleus is selected from each group as representative of it, as the packing fractions and the mass differences would be about the same for the others. When known, the accurate atomic mass is used; else, it is calculated from the packing fractions as obtained from the smooth curve between the packing fractions and the logarithms of the atomic masses. The packing fraction of the nucleus of mass 227 is thus taken to be 5. Δ is expressed as the difference of the masses of the constituents on the one hand and the mass of the resulting nucleus on the other. Therefore, positive values of mass defect, Δ , indicate endothermy and negative values exothermy.

The alternative hypothesis of the constituents being the light particles protons and neutrons can be also examined here. The results are set out in Table II of the syntheses of protons or neutrons taken ten at a time and the

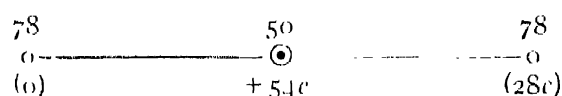
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masses of the nearest actual nuclei are shown for comparison. We observe that endothermy lasts till the synthesis of about mass 50 and gives way to exothermy at about 60. Again, if we assume a synthesis of the alpha particles to form nuclei, even for a nucleus of such large atomic mass as, say, 228, the disintegration would be endothermic. For, the packing fraction gives the mass of to be 228.114 while $57 \times 4.00216 = 228.122$. Thus, of the three hypotheses considered for nuclear syntheses, the proton hypothesis shows exothermy setting in too early, the alpha particle hypothesis indicates endothermy even for the heaviest nuclei, while the rare gas nuclei hypothesis shows exothermy to commence decidedly just with the radioactive nuclei.

RADIOACTIVE NUCLEI

Nuclei 206, 207, and 208. The three radioactive series, uranium, actinium and thorium, terminate in the end products of atomic masses 206, 207 and 208, all isotopes of lead, by successive alpha and beta ray changes. Our hypothesis reverses the usually ascribed role of parent and progeny, and these three nuclei are taken to be the parent ones from which the others ensue by further syntheses with alpha or beta particles. The rare gas hypothesis ascribes the structure $Kr + X$ to each of these nuclei. The nucleus 206 can be synthesised as $128 + 78$ or $126 + 80$ or $124 + 82$, the nucleus 207 as $129 + 78$, and the nucleus 208 as $130 + 78$ or $128 + 80$ or $126 + 82$. The sum of the masses of the constituents, the mass of the resulting nuclei, and the mass defects are shown in Table I. The disintegration of these three nuclei is exothermic and the energy given out ranges between 160 Mev and 168 Mev.

The structure ascribes to 206 is shown as follows :



There are the two equal end particles of masses 78 each at a distance 21 from each other, with a central particle of mass 50. An exchange particle of the proper mass and charge keeps moving between the end particles and keeps them tied up with sufficient energy. The central particle passes the exchange particle from side to side. Here we shall follow the procedure adopted previously (Soonawala, 1920, 1942) and the references are to the equations there. We can easily see that formula (16) is also valid for the three particle system used here. For, referring to the end particles as 1 and 2 and the middle one as 0, the wave equation of the system becomes

$$-\frac{1}{m_1} \Delta_1^2 \psi_r + \frac{1}{m_2} \Delta_2^2 \psi_r + \frac{1}{m_0} \Delta_0^2 \psi_r + \frac{8\pi^2}{h^2} (W_r - V) \psi_r = 0,$$

where W_r is the total energy and ψ_r the total wave function. If

$$\psi_r = F(x_0, y_0, z_0), \psi(r, \theta, \phi) \text{ and } W_r = W_F + W,$$

then, the equation gets separated into the two equations

$$\frac{m_1 + m_2 + m_0}{(m_1 + m_2)m_0} \cdot \nabla_0^2 \Psi + \frac{8\pi^2 W_1}{h^2} \Psi = 0$$

$$\text{and} \quad \frac{1}{\mu} \left\{ \frac{1}{r^2} \cdot \frac{\partial}{\partial r} \left(r^2 \cdot \frac{\partial \psi}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \cdot \frac{\partial}{\partial \theta} \left(\sin \theta \cdot \frac{\partial \psi}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \cdot \frac{\partial^2 \psi}{\partial \theta^2} \right\} + \frac{8\pi^2 \mu}{h^2} (W - V) \psi = 0,$$

where

$$\frac{1}{\mu} = \frac{1}{m_1} + \frac{1}{m_2},$$

with the usual transformations

$$x_2 - x_1 = r \sin \theta \cos \phi, \quad y_2 - y_1 = r \sin \theta \sin \phi, \quad \text{and} \quad z_2 - z_1 = r \cos \theta.$$

The moment of inertia of the nucleus (Soonawala, 1942) 206 is $1.007 \cdot 10^{-46}$, and this is also equal to $2 \times 78 \times 1.67 \times 10^{-24} \times r^2$, from which $r = 1.72 \cdot 10^{-12}$ cm. We take this to be the range $1/\lambda$, and calculate the mass of the exchange particle from (21). This comes out to be 22.35 times the electronic mass.

To find the potential depth V , we now take $E = +e$, [eqn.(10)]. With $M = 78 \cdot 1.67 \times 10^{-24}$, $e = 2.705 \cdot 10^{-4}$ erg, $2\pi \sqrt{Mc}/h\lambda = 310$, Eqn.(68) becomes

$$\frac{d^2 u}{dx^2} = - \frac{4\pi^2 Mc}{h\lambda^2} u$$

giving as the solution

$$u = C \cos \left(\frac{2\pi \sqrt{Mc}}{h\lambda} x \right)$$

Therefore,

$$u' = C \cdot \frac{2\pi \sqrt{Mc}}{h\lambda} \sin \left(\frac{2\pi \sqrt{Mc}}{h\lambda} x \right)$$

and

$$\frac{u'}{u} = \frac{2\pi \sqrt{Mc}}{h\lambda} \tan \left(\frac{2\pi \sqrt{Mc}}{h\lambda} x \right).$$

Joining up the two values of u'/u as in (73), at x_0 ,

$$1 - a/2 = 1 - \frac{4\pi^2 M_1 V}{h^2 \lambda^2} = 1 - 1.03 \cdot 10^{20} \cdot V = 310 \cdot \tan(310x_0).$$

Assuming x_0 to be equal to about 10^{-12} cm, $310x_0$ is small enough for $\tan(310x_0)$ to be equal to $310x_0$. Hence,

$$1 - 1.03 \cdot 10^{20} \cdot V = 310 \times 310 \times x_0.$$

The term on the right hand side is so small in comparison with unity that

$$1 - 1.03 \cdot 10^{20} \cdot V = 0, \text{ and } V = 9.7 \cdot 10^{-21}.$$

We should get closely similar values for the constants of the nuclei 207 and 208.

Nucleus 227.—It is known for certain that krypton is one of the primary products of uranium fission and at least four of its isotopes have been discovered. It is also almost certain that xenon is another such primary particle

(Meitner, 1945). The two particles given out during fission are always of masses similar to those of xenon and krypton. Very probably, Kr^{88} and X^{139} are such primary products, Sr^{88} and Ba^{139} being their end products (Heyn, & others, 1939). The combination of these two nuclei gives a nucleus of mass 227, which would be actinium or an isobaric of it. The disruption of this nucleus would be exothermic as seen from Table I. The mass defect is 0.25 unit, which is equal to $3.76 \cdot 10^{-4}$ erg, or 236 Mev. The potential depth, calculated as for 206 above, is $1.7 \cdot 10^{-20}$, and the mass of the exchange particle $21.97 \times m_e$. This nucleus is an illustration of the principle noted above that we can have two nuclei of the same atomic mass and number but different in constitution. For, above is shown a two particle structure of 227, while commencing with 207 we can have a six particle structure with five alpha particles added to the nucleus 207. Another example would be to consider radon as a rare gas nucleus and follow up the radioactive series to 226, 230, 234 and 238.

TABLE I

Nucleus and its mass	Masses of constituent nuclei	Mass defect	V	M	2r
Na 21.0035	19.9988+1.00812	+0.0034	...	...	...
Mg 23.9924	19.9988+4.00216	+0.00956	3.8×10^{-18}	29.05	1.37×10^{-12}
K 39.975	38.9755+1.00812	+0.00862	...	...	...
Cu 39.974	35.9780+4.00216	+0.00616	...	...	...
Ni 57.942	39.971+17.997	+0.026	...	...	...
Br 80.926	79.926+1.00812	+0.00812	...	...	...
Sr 87.931	83.928+4.00216	-0.0008	...	...	...
Mo 99.915	79.926+19.997	-0.022	3.5×10^{-20}	20.83	1.85×10^{-12}
Cd. Sn 119.912	79.926+39.971	-0.015 = 14 Mev.	...	...	...
Cs 132.933	132.930+1.00812	+0.00512	...	...	...
Ba 137.916	133.929+4.00216	+0.01516	3.8×10^{-18}	7.01	5.47×10^{-12}
R. E. I (143.93)	123.93+19.997	-0.003	...	...	...
R. E. II (160.92)	131.93+37.97	-0.02	...	...	...
RaG 206.038	125.932+79.926	-0.18 = 167.6 Mev	1×10^{-20}	22.35	1.72×10^{-12}
AcLead 207.038	128.930+77.926	-0.172 = 160.1 Mev	...	...	...
ThLead 208.039	127.936+79.926	-0.177 = 164.8 Mev	...	...	...
Ac 227.114	138.93+88.93	-0.25 = 236 Mev	1.7×10^{-20}	21.97	1.75×10^{-12}

M is the mass of the exchange particle expressed in the electronic mass, 9.038×10^{-28} gm, as the unit.

2r is the distance between the end particles in cm.

R. E. I and R. E. II refer to the two rare earth groups.

Nuclei 235 and 239.—These would result from addition of three or four alpha particles to the nucleus 227 with slightly higher energies of fission.

Neutrons are also known to be the product particles of uranium fission ; and if they are assumed to be among the primary product particles, then the above constitution of nucleus 227 would be revised to something like $X^{138} + Kr^{87} + 2.n. = 227$. This is on the assumption that two neutrons are emitted in the fission of 227. The energy of fission is, then, $3.517.10^{-4}$ erg, or 221 Mev. V cannot, of course, be calculated as before. Similar considerations would apply to another nucleus, such as, say, 206.

A few values of the potential depth are shown, and these are necessarily approximate. Even then we can discern a definite trend for the relatively unstable and exothermic nuclei to have systematically smaller values of V , indicating proportionately smaller binding forces between the constituent particles.

TABLE II

n	$10 \times n \times 1.008$	Mass of nearest nucleus
1	10.08	10.00
2	20.16	20.00
3	30.24	29.98
4	40.32	39.97
5	50.40	49.95 } 50.95 }
6	60.48	59.94 } 60.94 }

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